Vertical Hydroponic System

University of Ottawa

Course: GNG1103A

Submitted to: David Knox

By: Group A7

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Abstract

This report covers the steps that we took in our design thinking process to develop a final solution for our hydroponic system. Starting from understanding our customer's situation we defined a problem statement that our team needed to solve. Our system needed to be cost-effective, easy-to-use, easily maintained, and does not require electricity. Each member thought of ideas and solutions. We converged and analyzed our ideas to use the best solutions. We created prototypes, tested the prototypes, obtained feedback, and iterated based on that feedback. Our system is superior than other hydroponic systems because it can grow a large quantity of crops without the use of electricity.

Table of Contents

List of Figures

List of Tables

Acknowledgement

All work has been completed and researched by the group members listed on the title page. We would like to thank our teacher's assistant and our client Mohammed Ali for providing feedback and providing information about Syrian refugees in the Jordan region.

1. Introduction

The country of Syria has been torn apart by a civil war and turned their cities to dust. Many have been killed and millions have been forced to flee their country. Those who managed to escape, women and children, fled with only things they could carry by hand. Currently a majority spend the remainder of their lives in refugee camps scattered across the region of Jordan. Those displaced millions have sought to create moments of normalcy in the temporary rooms, mud floored tents, and makeshift shelters, waiting for their country to stitch itself back together.

Hydroponics is the method of growing plants without the use of soil, it uses a nutrient solution instead to deliver nutrients to the plants. This system will prevent famine, saving many lives since the refugees will be able to produce crops in their barren lands. This system allows refugees to cultivate their own crops without using their dry soil and limited resources.

Our hydroponic system is unique compared to the rest of the hydroponic systems out in the market because it has a large capacity for crops despite taking up less space and it requires no electricity. Our system is a vertical hydroponic system it saves space because the crops will grow in rows of pipes. This allows our system to save the area it uses by increasing the height of our system. It also has the option of removing parts, this allows a cheaper product because it will be able to be supported by the caravans instead of added materials. Lastly, our system is fully manual and requires no electricity to function.

In the following sections, the design thinking process is used to explain how we arrived at our final solution.

2. Empathize

Empathizing with the customer is the first process of our design thinking phase. It allowed us to understand their given conditions and properly assess their issues. We were fortunate enough to have interviewed Mohammed Ali, a former refugee at a Jordanian camp, since he could share his experience as a refugee with us.

Escaping from the civil war the refugees were put in small camps. They were given limited resources; a barrel of water per day, a box of dry food, and a minimal amount of money per month. The money they received is usually spent on produce. They were also given no electricity except for a generator that is used to power their only source of light at night.

The refugees currently live in a desert. They are unable to grow their own agriculture because of the dry infertile soil, and the drastic temperature changes ($0 – 40^0$C). Previously, students from France have visited the camps and invented filtration systems to recycle the used water. The filtration system allowed them to be able to grow small agricultures like cilantro, but failed to grow any other due to the soil.

After interviewing Ali, we have a clear understanding of the refugees needs and wants. The refugee’s needs are to ensure survival therefore, access to food and water is crucial for

them. However, they want to be able to provide for themselves and grow their own agriculture. Lastly, they have stated the importance of electricity in their lives.

3. Define

The second process of the design thinking process is defining. After interviewing Ali, we determined the refugees need and wants but more importantly we were able to define a problem statement that captures it all. The problem statement that we have defined for this project is the following:

The refugees need a hydroponic system that allows them to cultivate agriculture under harsh weather conditions. It is crucial that the system is easily operated and maintained by the refugees, and that it is cost effective for the buyer.

After having defined a problem statement that captures the essentials of the problem at hand we could move on to the next step of the design thinking process, which was to generate ideas.

4. Ideate/Plan:

4.1 Ideate:

To design our own project, we used the strategy that expand our idea first and condense these ideas later. To broaden our knowledge in hydroponics, we first researched some basic information of hydroponic systems. We learned there are six different types of hydroponic systems. After weighing the pros and cons of each type we decided to design based on either a wick system or a deep-water culture system. The benefits of a wick system are that the system is a “Truly “hands off” if you set it up correctly” [1] and it is “Fantastic for small plants, beginner gardeners, and children” [1]. The benefits of a deep-water culture system are that the system has “Minimal growing medium needed” [1] and because the “Recirculating system means less waste” [1].

To understand the competition and current hydroponic system specifications we researched the existing products from 4 different companies. We collected the information, analyzed it, and organized it to determine the target specifications, functional and non-functional properties and the constraints of the system as shown below:

<u>Functional requirements</u>

- Filtration system
- Water reservoir capacity
- Simple design (easy to set up/maintain)
- Leak proof
- Pest proof
- Nutrient and water recyclability
- Man powered or devoid of use of energy
- Stability

Constraints

- Cost ($)
- Dimensions (LxWxH (m))
- Weight (lbs/kg)
- Capacity (L)
- Temperature (°C)
- Operating conditions: Temperature

Non-functional requirements

- Product life (years)
- Aesthetics
  Reliability

The information above was used to make our design criteria. Then, based on the user's needs, we assigned different weight to each criterion. For example, the cost and recyclability has the most points because these are related to constraint factors. Capacity has the second most points because the amount of growing plants is also important. That information was used to benchmark our competition as shown in table 1. Based on the best product in our benchmark analysis we created our target specifications, as shown in tables 2 - 4. We also use target specification table to show the ideal performance and real performance to help us understand the system better.

We were looking for as many ideas as possible, so we diverged into different ideas through sketching. We had almost twenty ideas as shown in figures 1 - 11, and we discussed them without judgement. We refined those ideas to make a final design. We removed huge or high-tech designs from out list because of the environment and working capital of the refugees. After integration, we finally concentrated the ideas to three main concepts, a vertical water culture system, a vertical wick system, and a horizontal deep-water culture system as shown in figures 12 - 14. To make the final decision from these three concepts, we made an evaluation table as shown in Table 5 to help with our judgement.

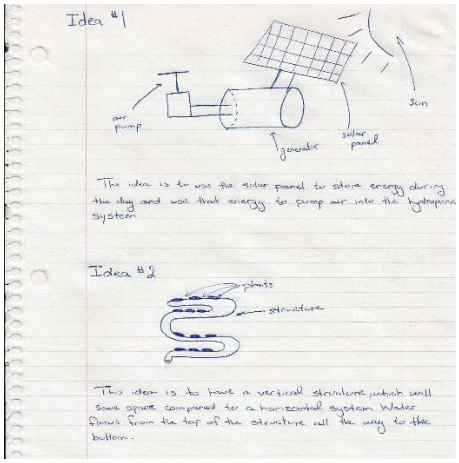


Figure 1

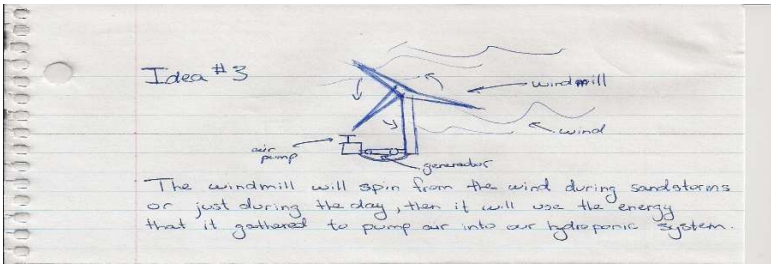
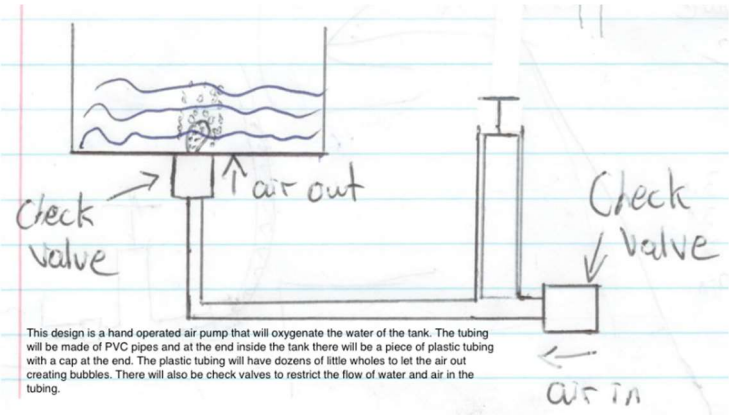
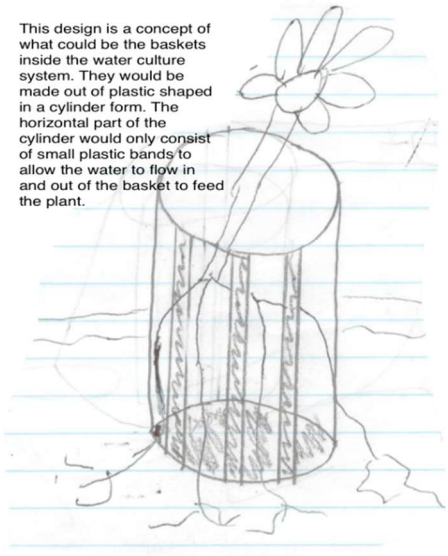


Figure 2



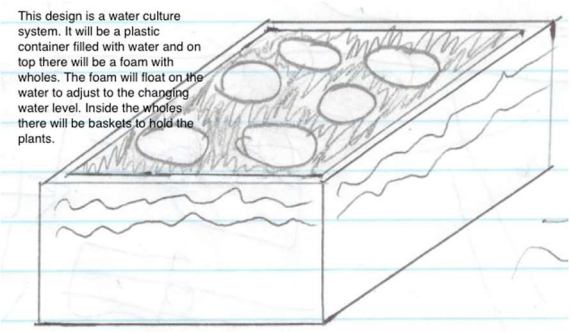
This design is a hand operated air pump that will oxygenate the water of the tank. The tubing will be made of PVC pipes and at the end inside the tank there will be a piece of plastic tubing with a cap at the end. The plastic tubing will have dozens of little wholes to let the air out creating bubbles. There will also be check valves to restrict the flow of water and air in the tubing.

Figure 3



This design is a concept of what could be the baskets inside the water culture system. They would be made out of plastic shaped in a cylinder form. The horizontal part of the cylinder would only consist of small plastic bands to allow the water to flow in and out of the basket to feed the plant.

Figure 4



This design is a water culture system. It will be a plastic container filled with water and on top there will be a foam with wholes. The foam will float on the water to adjust to the changing water level. Inside the wholes there will be baskets to hold the plants.

Figure 5

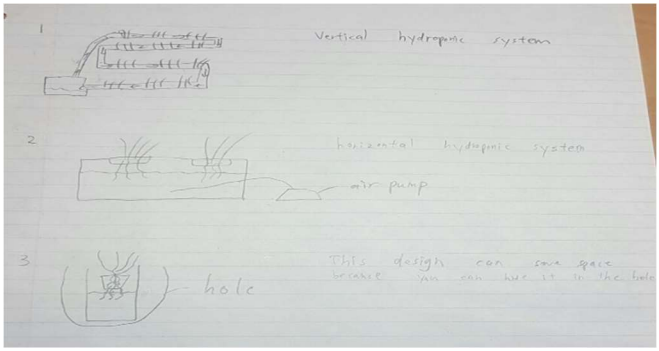


Figure 6

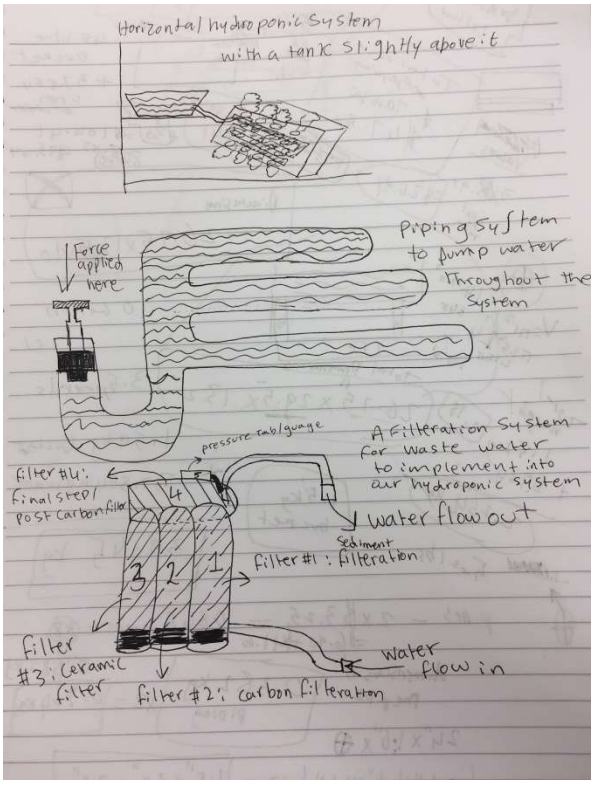


Figure 7

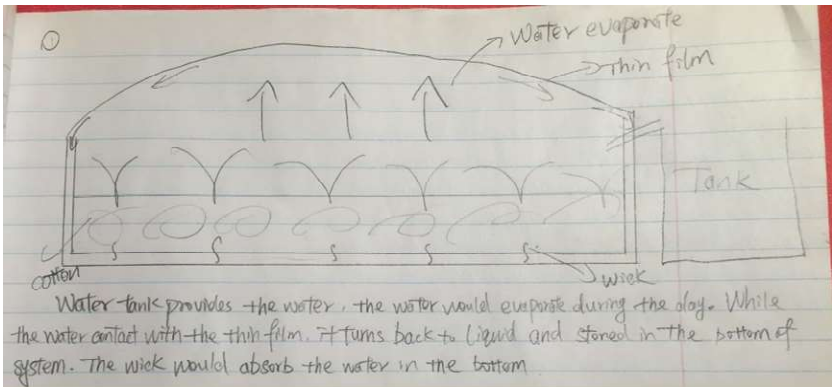


Figure 8

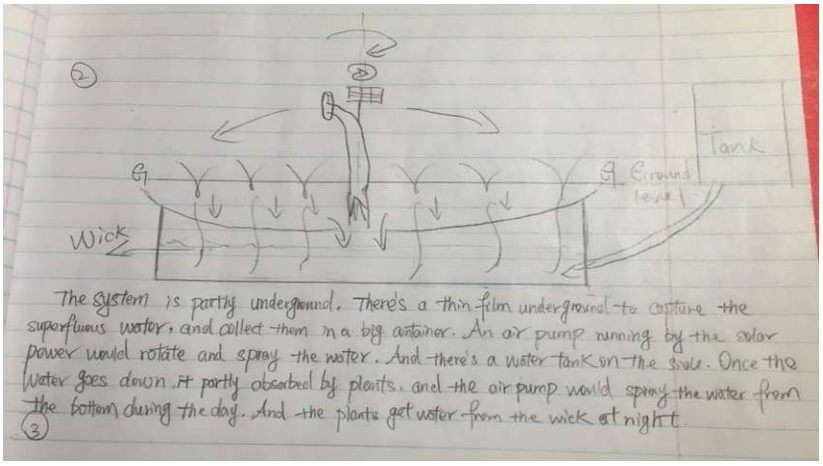


Figure 9

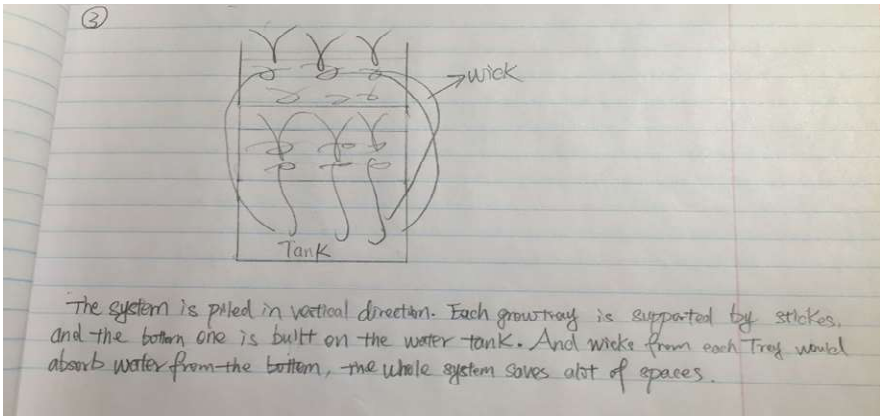


Figure 10

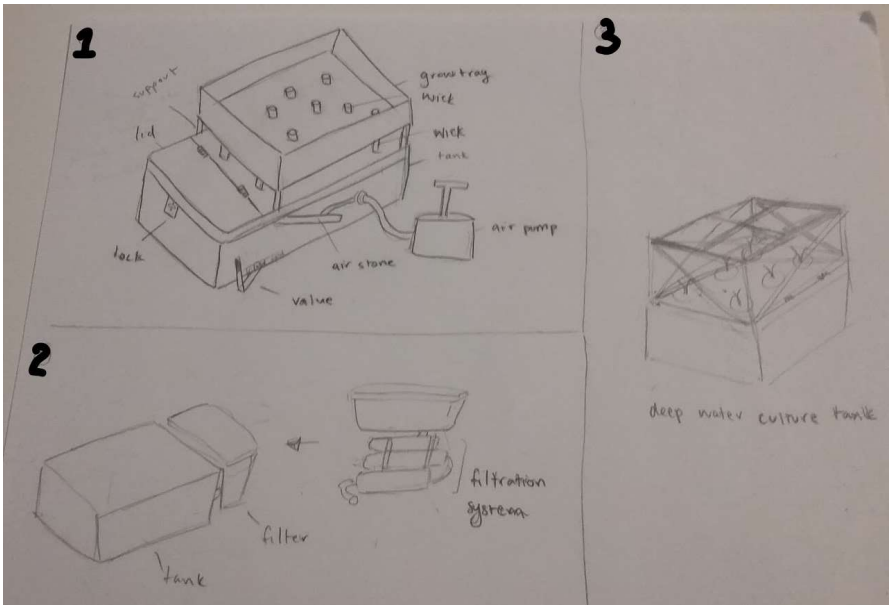


Figure 11

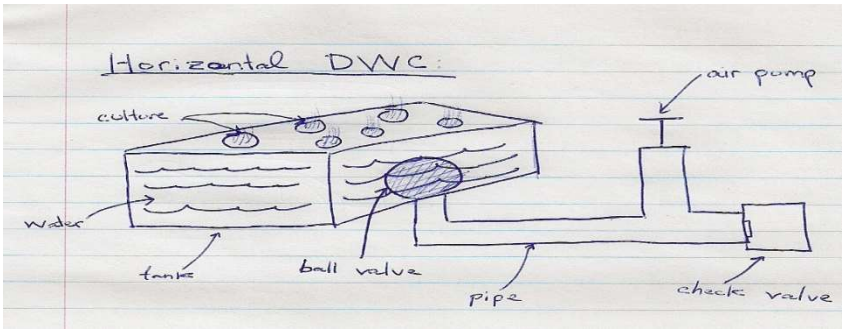


Figure 12

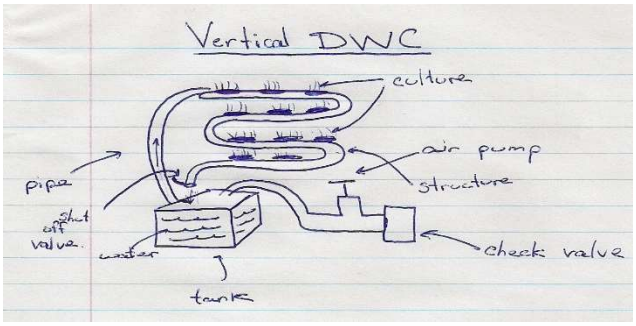


Figure 13

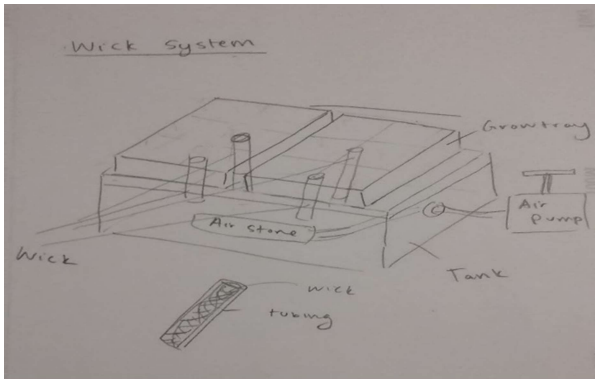


Figure 14

Table 1: Benchmark

(4 = Green, 3 = Yellow, 2 = Orange, 1 = Red)

Company	Importance (weight)	Powerhouse Hydroponic	Autopot USA	Sales 5	Viagrow
Cost ($)	5	107.30	79.95	101.37	139.99
Dimensions (LxWxH) (in)	4	Grow tray (20x2x5) (0.12 ft³) Tank (12x8x6) (0.33 ft³)	Grow tray (9.6x7.8x7.6) x2 (0.66 ft³) Tank (14.5x11x24) (2.22 ft³)	38x28x20 (12.31 ft³)	42x36x14 (12.24 ft³)
Weight (lbs)	3	6.4	7.6	6.0	25.0
Recyclability	5	Yes	Yes	Yes	Yes
Filtration	2	No	Yes	No	No
Capacity (L)	3	9.46	16.66	50.00	75.72
Material	3	glass/steel	plastic	plastic	plastic
Total		62	74	78	66

Table 2: Functional Requirements

	Design Specifications	Relation (=, < or >)	Value	Units	Verification Method
1	Filtration system	=	Yes	N/A	Test
2	Water reservoir capacity	=	20 to 80	Litre	Analysis
3	Simple design (easy to set up/maintain)	=	Yes	N/A	Analysis
4	Leak proof	=	Yes	N/A	Test
5	Pest proof	=	Yes	N/A	Test
6	Nutrient and water recyclability	=	Yes	N/A	Test
7	Man powered or devoid of use of energy	=	Yes	N/A	Test
8	Stability	=	Yes	N/A	Test

Table 3: Constraints

	Design Specifications	Relation (=, < or >)	Value	Units	Verification Method
1	Cost	<	100	$	Estimate, Analysis
2	Dimensions	<	13	ft^3	Analysis
3	Weight	<	20	lbs	Analysis
4	Capacity	=	20 to 80	Litres	Analysis
5	Operating conditions: Temperature	=	-5 to 45	°C	Test

Table 4: Non-functional Requirements

	Design Specifications	Relation (=, < or >)	Value	Units	Verification Method
1	Product Life	>	7	Years	Test
2	Aesthetics	=	Yes	N/A	Test
3	Reliability	=	Yes	N/A	Test

Table 5: Evaluation Table

(3 = Green, 2 = Yellow, 1 = Red)

Design	Importance (weight)	Vertical Water Culture	Horizontal Water Culture	Vertical Wick System
Cost $	5	160	110.44	65
Dimensions (LxWxH) (in)	4	120.00 x 16.00 x 48.00	26.75 x 17.50 x 10.00	Grow Tray 10.98 x 22.01 x 4.02 Tank 13.75 x 32.00 x 19.0t0
Weight (lbs)	3	62	5.02	8
Recyclability	5	Yes	No	No
Filtration	2	No	No	No
Capacity (L)	3	130	37.9	100
Estimated Capacity (Plants)	5	60	10	12
Material	3	PVC/Plastic	Plastic	Plastic
Total		70	47	61

The first design criteria that we have focused on were cost. Since, the cost of the system depends on whether the refugees or non-governmental organizations (NGO) will be able to afford or even consider purchasing it. Another criterion that we have chosen was weight because it is important that the system is light. Since, our client mentioned during the interview that the camp faces sandstorms and if the system is too heavy then it will be difficult to move the system indoors. The standard of recyclability of the water was chosen because the Syrian

refugees are struggling with water shortage, so the ability to reuse water is a key aspect for our hydroponic system. Filtration is a very important concept for our system but unfortunately to maintain the other criteria such as cost we were unable to incorporate it into our final design. We had benchmarked a product which included a filtration system and the cost was relatively cheap. We are trying to understand how the company managed to keep their prices low with a filtration system which was found to be expensive in the market. We conducted research on the product and found that the material that was used was cheap plastic and the product life was at a maximum of 2 years. Even though none of our designs incorporate a filtration system we think that the criteria itself is very important. The capacity of the tank is important because it determines how much water the system can hold and it implicitly determines how many plants can grow in our system. Plant capacity is important because if a system can hold more plants that means that the users are able to grow more crops and save time and money. Lastly, the material of the system is one of our design criterion because the type of material determines the price of the system, how long it will last and other non-functional requirements.

Therefore, after considering our design criteria such as cost, weight, dimensions, capacity, material, filtration and recyclability system, as shown in table 2. We determined that our global concept is the vertical deep water culture. The vertical deep water system was ranked highest in our selection matrix as it incorporated most of our design criteria and it was found to be the most practical system for our case. As our client mentioned, the weather is very hot and there are chances for sandstorms. The vertical system can withstand the harsh heat and due to its weight, it is also able to withstand heavy winds. Although it has the most cost among three concepts, after calculation, it is the cost effective for the price compared to the amount of plants it can grow. It has a large water capacity to store additional water. It is the only model that can recycle the water, which saves on wasted inputs. The group decision is to pursue the vertical system as our global concept and we will continue to look to improve our system. The next step is to develop our prototype and ensure we cover all our steps. We will also need to do more research about which material would better suit our concept.

4.2 Plan:

In this step of the design thinking process we planned our future work and how to complete our prototypes on time in order to receive feedback from Ali. First, we made a list of all the tasks needed to be completed. Most of our tasks consisted of our prototype deliverables divided in different sections, which were: developing improvements for the prototype, purchasing the required material for the prototype, making the prototype, and evaluating our prototype. The next step was to estimate the duration of each task. To do this we divided the amount of time between the end and start dates of each deliverable by the tasks. We allocated more time for the longer tasks and less time for the shorter tasks. Each week was similar, since each prototype had the same tasks. Although it varied a little because the prototypes were not the same. The final presentation and the final report were also included in our plan. The next step was to assign the tasks to the group members. To do this we created a “signup sheet”. Group members could assign their own tasks, the more committed and responsible team members’ names were more recurring. For the final presentation and report all team members worked together to complete both tasks. Finally, we created a Gantt chart in Microsoft Project Professional where all the tasks were clearly stated and the team member(s) assigned to each task. The estimated duration was also in our Gantt chart; in addition to adding the dependencies of each task on the others.

Meanwhile, while following the project schedule to the best of our ability, we started planning for the consecutive prototypes. Given a budget of $100, we had to minimize the costs of building each prototype.

For Prototype 1 we had a maximum budget of $5 for any necessary tools and materials that we had to buy. We had a low budget for this prototype because we planned to use materials that are found around the house or that were already available to us such as straws and cardboard.

For prototype 2, we would build the pump in our system. We planned a budget that should not exceed $30, to leave as much money as possible for the last and final prototype.

Finally, for the 3rd and final prototype, we would be allowed to use the remaining $65-70 dollars of our budget. However, we had calculated the price of the minimal materials that we needed to purchase. We used Amazon, Walmart, Home Depot, and Canadian Tire to research costs and compare prices.

The expected delays and risks we expect to happen are:

- Purchase and shipment delays
- Material failures
- Operation failures
- Testing errors

We made contingency plans for each risk. Purchase and shipment delays would be mitigated by purchasing materials earlier. Material failure would be mitigated through prolonged research before purchasing materials. Operation failures of our system would need to be monitored by our team members. Lastly, testing errors would be mitigated by adding a margin of error for example the temperature ranged from 0 – 40^{0}C and we would test at -5 – 45^{0}C.

5. Prototype/Test

5.1 Prototype 1:

Our first prototype is a basic proof of concept, we planned to test whether the nutrient solution will be able to be distributed to each plant as shown in figure 15 – figure 17. But, due to the limited materials we created a model that shows the structure of our final design. We had a time limit of 3 days and a budget of $0.00 - $5.00 to build our prototype. This prototype showed our client Rob Hunter the layout of the system and how it will distribute the nutrient solution to the plants. To build our first prototype, we used: scrap wood, straws, hot glue, plastic bottle and wooden sticks.

5.1.1 Test

The purpose of this test is to ensure that the most crucial aspect of our system (the flow of the water pumped by the air pump) is running smoothly. We decided to test this aspect because it represents the main step in the creation of the system. The reason is to ensure us as producers that the structure of our system is efficient, stable, and possible to create in real life. For example, the structure of our hydroponic system is made from horizontal pipes which will allow us to grow our plants vertically. It also allows us to determine whether growing plants vertically is possible by confirming if the system is stable, effective and if it will cut down in cost

and space. The test will also be used to learn about the flaws of our system.

The specific test objectives are the water nutrient solution distribution and maintenance of the water nutrient solution. The objectives of the test are to determine how often the user changes the water and how often they need to add nutrients. These simple objectives will allow us to test the most vital aspect of our system. Optimal concentration of nutrients and pH are required to maintain a favored environment for the plant to grow in. After quantifying the amount of plants, this will lead us to the following step of determining how much nutrients needs to be added to the water tank. The concentration of nutrients and pH are dependent on the quantity of plants built on the pipe.

The test is successful if the water flows through the system at an average velocity and allows the water to flow through each hole without overflowing or underflowing. The test is a failure if the water flow is either too strong or too slow to completely fill the holes.

These results will be used in the future to make the decision to add a water reservoir at the top of our system or not. If the flow of the water is too strong, we should add a water reservoir on top of the tank to slow down the water so the water won't overflow the system or damage the roots of the plants. These results will also be used as selective concepts to change such as, moving the position of the current water reservoir to a more suitable location closer to the plant holes. A constant water flow and low pressure is required so the water will not damage the roots. Moreover, proper size and height of the water tank determines the number of pillars required to support the structure mechanically. Lastly, resistance of the water pipe and proper circumference and area of the opening should take in count.

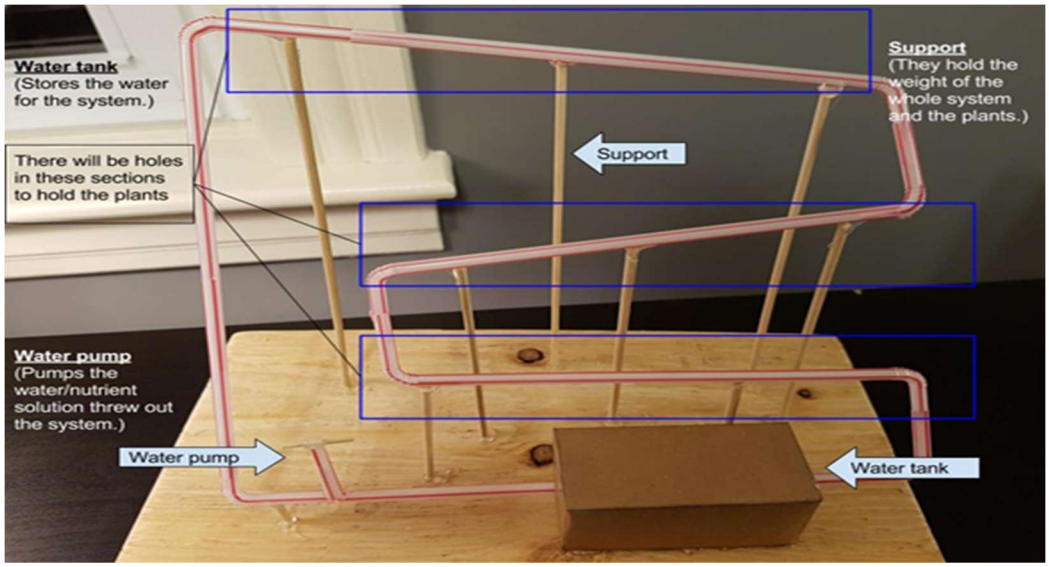


Figure 15: Prototype 1.1

Figure 16*: *Prototype 1.2 Plant Holder

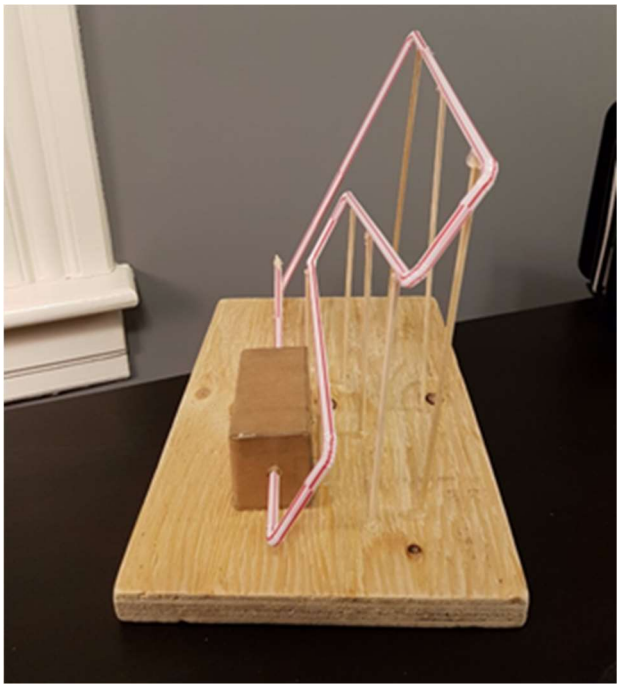


***Figure 17*: Prototype 1.3 Model System**

This prototype is built from household materials because the purpose of the prototype is for understanding the concepts of our system and testing them. The main structure of the prototype is made from connecting drinking straws and using hot glue to connect them. Our first idea was to use plastic water bottles for the main structure of the system but then we came across the problem of how to bend the water bottles and then connect them, so we have chosen to use straws to make it simpler. Also, the air pump is built using straws because it is used for demonstration purposes for example the location of the pump. We will be covering the air pump in depth in the next prototype. We have used thin wooden sticks as support to hold the system up in this prototype and have glued everything to a wooden block for demonstration purposes. We have decided to build a miniature, non-functional version of our system because it will allow us to determine if there are any major flaws with our system and we will be able to reduce the risk.

Since our prototype is non-functional, constructing real life tests will not be possible but we have made the following assumptions for our prototype test. Without building the air pump, which we plan to build in our next prototype, we have assumed that the air pump is functioning properly which will allow the flow of the water to run through the pipes of our system allowing the plants to feed on the nutrients. The design of our system is to use the earth's gravitational pull to aid the water flow cycle, as the pipe from the air pump to the first plant is a vertical path Figure 2 so the air pump will be the trigger of the flow allowing the water to flow to the top of the system then gravity will help the flow because our pipes are built at an 85-degree angle to the previous pipe allowing water to flow gently. Also, we have decided to add a water reservoir just before the water flows through the pipes containing the plants, to balance the speed of the water allowing a gentle flow.

Our customer thought that our design was good and simple but could be improved. One concern was that pumping the water through the tubing could create a turbulent flow which

could damage the roots and the plants. To prevent this, we will add a water reservoir at the top of our system. Water will be pumped into the reservoir and with an on/off valve we can let the water flow softly and at a constant rate from the reservoir. The second suggestion was that the system would not able to grow plants from seeds because the holder was too big for the seed. To fix this design flaw, we will add a growing media that prevent the seed from falling out of the holder while also helping to distribute the nutrient solution. The final comment was the customer was not provided with information to maintain the system. To implement this, we will have the instructions on a sticker that will be placed on the finished product. To be able to make precise instructions, we need to determine the capacity of our system which will only be found while doing prototype 3.

After completing our first prototype, we have identified improvements to our system and schedule. Those improvements include an additional water tank at the top of our system, a subsystem that will allow users to grow plants from seeds and simple instructions to maintain the system. The next step of our project is to make our second prototype. Our second prototype will be used to test our pump. We will be testing if the pump will be able to bring water to the height of our system. Our first prototype was a success. We were able to provide a proof of the concept to show that it would be effective to grow plants, save space, and avoid the use of electricity.

5.2 Prototype 2

Our second prototype is a focused prototype which we decided to work on the water pump, as shown in figure 18. It is the most critical component in our system because if the water pump were to fail then the whole system would fail as well. To help us build a better pump, we did research on designs that were already on the market. Our design is made from plumbing material only. The pump is made of ABS pipes where some pipes can go inside other pipes. The inner pipe would have a plug at the end, while pulling the pipe up it would create suction and while pushing down it would create pressure. At the end of the pipe there would be a T shaped fitting to allow water to come in from one side and out from the other. This will be possible using one way valves placed in the opposite direction on each side. On one side as you pull on the pump the valve would open and let the water in, while the other would be pulled shut. When pushing on the pump it would be the opposite valve that would open to let the water flow out. All the pipes and valves will be connected using fitting, ABS cement and Teflon.

Figure 18: Prototype 2 Air Pump

The reason why we have decided to make a PVC water pump is because it would be cost effective since we only need to buy the pipes and connectors then build the pump ourselves. Secondly, we require a manual pump as there is no electricity in the refugee camps to operate an air pump. Considering these facts, we concluded that a homemade PVC air pump would be the best option.

For this prototype, we had given ourselves a budget of 30$. Unfortunately, we were unable to find some of the materials we were looking for which caused us to go over the budget by a little. First, we needed pipes which cost 4.83$ for 2 feet of 2-inch pipe. The other pipe of 1-½ inch we could find for free. Next, we needed 2 check valves of 8.97$ each. Then to connect everything we needed fitting. All the fittings combined they cost 15.92$. All this material comes up to 38.69$. Although we did go over our budget it was not by very much. Also, we bought other material for testing but this material will be used to build our third prototype which means that the cost of those materials will go in the prototype 3 budget.

5.2.1 Test:

In our prototype testing we observed whether the water flowed through the six-meter flex pipe. Before conducting our test, and building our prototype we needed to do research and model the different parts of our system such as the type of tubing, the type of pipes, the diameter of the pipes and tubes, and the height at which we planned to test our system. We needed to research which stores carries the required pipes and tubes that offers the best price.

Before we were ready to test our prototype, we first bought all the required material to build our prototype which took a couple of hours. Then to build the prototype it took the rest of the day. After having completed the following tasks, we built a testing plan to ensure that we knew what we were testing and the success criteria for our test. When all the above tasks were completed, we tested our prototype which will took about an hour to fully complete the test and record our results.

The testing process was the following steps, we first built the air pump after having bought all the required materials, then we took our prototype outside where it will not matter if water spills everywhere. We took two large pales, about 3.78 L in capacity, then filled one of them up with water until it almost reached the top. We fit a rubber flex tube to one end of the air pump and put the open end of the tube inside the empty pail. We then placed the other end of the pump inside the pail with water then pumped water from one pail to another. While the water was being pumped, another person was timing the person, how long it took him to pump all the water. We then took the water that has just been pumped and put it in cups to measure how many litres it pumped in the time. We then repeated the test 2 more times to make sure our results were consistent and that none of the tests were a fluke. We then recorded our results and performed simple mathematics to solve the pumping rate per minute.

First, we tested to see if the water would flow through a six-meter bent and dented flex pipe. This was a true or false test if it could flow through all six-meters then the test was successful and if it couldn't it had failed. After testing the pump 5 times we concluded that the test was successful. If the test had failed we would have retried the test at a lower max height. We tested to see the max height of the system, but it had exceeded expectations and was able to pump through all six meters of tubing. Our system was expected to be approximately one meter in height. Therefore, our pump was successful and we can move on to our next test.

Table 6: Prototype 2 Flow Rate Test

Trial	Water (L)	Time (s)	Flow rate (L/min)
1	7.334	36	12.22
2	7.314	35	12.54
3	7.286	38	11.50
Average	7.311	36.33	12.09

The second test of our prototype was to determine the average time it takes to pump water. This test was not necessary for the system to function, but it is useful information for the user. This test determined if the pump will be easy to use for our user.

We completed three tests and compiled the results as shown in Table 3. We calculated flow rates in case of changes to the length of piping, and the amount of water needed to fill the water tank at the top of our system. We had filled the pails with water and tested to see how long it would take someone to transfer water from one pail to another. After conducting three trials of the experiment, the average volume of water we pumped was 7.3L on an average of 36.3 seconds. We then concluded that the average flow rate of the pump is 12.1L/min. The water pumps fast enough therefore, the work required to pump water is acceptable for users to maintain the system manually.

After having performed our tests we went out and received customer feedback from Mohammed. Our prototype was well-received however, our client had a few concerns and suggestions. The client was concerned about filtering water before using it in the system and how our system will recycle and filter the water that is already being used in the system. Other than those concerns our client complimented our design choices. The client was satisfied with the dimensions of our system and the capacity of plants it is estimated to grow. The client was impressed with the fact that our design does not require electricity.

To address our client's concerns, we considered solutions already in place at the refugee camp and new solutions. Previously, students created a filtration system to reuse the wasted water from showers, and cleaning. We believed that the solution already in place will be sufficient in supplying clean water to our system. However, we should have considered solutions for other potential customers that may have a shortage of clean water. One suggestion from our client was to have a membrane to remove dirt from the water before use.

Apart from presenting our prototype to our client we asked some questions for future prototypes. Our questions focused on the dimensions of their caravans and whether it could support the weight of our system. We discovered that the caravan is large and sturdy enough for our system. Another question we asked was whether the families are willing to share a hydroponic system. The client answered that it was a good idea that they could share it. This enabled us to build a larger system that would be cheaper for the refugees overall.

After completing the prototype there are obvious adjustments we will need to make. First, prototype 2 went over our budget. Like prototype 1, the prototype took a shorter time than expected while gathering feedback, testing, and analysis took longer than expected.

Based on our feedback most of our design criteria had been addressed. Key functional requirements and constraints had been tested and approved by our client. Our system proved that it can function without the use of electricity. Our system is simple and easy for the client to use, the dimensions and cost are within our limits, the system recycles water, and the client approved of the aesthetics of our design with horizontal piping. Based on our design criteria we still needed to test a simple filtration system and test whether the system would be able to endure high temperatures.

After completing our second prototype we have come across some complications that needed to be addressed in the future to ensure a smooth and successful prototype III. These complications included customer feedback problems, budgeting, and the overall design of our system.

For the next prototype, we planned to get feedback at an earlier stage because this will allow us to consider implementing the improvements given to us from our potential client. Also, making an appointment with clients at an earlier stage allowed us to reschedule in case the client is unable to attend for an unexpected reason.

Since we had gotten feedback from our client at a later stage of our prototype we were unable to implement the improvements, but we planned to make the necessary changes to our third and final prototype such as incorporating the idea of a water filtration system and a support system against the caravan.

We had to adjust our budget plan since, we had gone over our budget by about $10.00 for the prototype. We adjusted the future prototype so that we do not surpass our budget limit. One solution we planned to implement it to not purchase a tote for our water tanks. Instead we continued using the pails that we were using for free. This will effectively nullify the excess costs of the prototype.

The next step of our project was to make the third and final prototype. Our final prototype will be the whole system and we have used our knowledge and understanding of our first and second prototype to built it. This prototype will be used to the test the overall function of our system. We will be testing to see if the system will be able to keep the water flowing throughout its body and allow the cultivation of the planted agriculture.

5.3 Prototype 3

Our third and final prototype is a full representation of our system and it is fully functional, as shown in figure 19. Creating this prototype was the most demanding task out of all our design process. It is also one of the most crucial points. This model allows us to test our actual product and make sure that it is functional. We started by creating a plan for building the prototype and testing it.

We based our design on our first prototype and added some modifications based on the feedback we received. The main addition was that we added a water tank at the top of our system to prevent damage to the roots due to harsh water flow. We decided to build 2 rows of plants using PVC pipes. We determined that we needed around 8 feet of PVC pipes. We needed 3 90º PVC elbows to connect the 2 rows and to go in the bottom tank. For the support of our system it consists of a wooden frame and will be held together by wood screws. To hold the pipes to the frame we decided to use metal straps screwed to the frame. These straps are solid and can support a lot of weight. For the bottom water tank, we went with a simple water pale to save money. In our final product, there would be a lid to prevent evaporation. From the bottom tank, we made a small section of ABS pipe to connect to the pump with some 90º ABS elbows. This required 3 elbow and approximately 2 feet of 1-½” ABS pipe. It also required some fittings to connect to the pump. On the other side of the pump we connected a 1” clear flex hose because it allows more freedom when choosing the position of the pipe compared to PVC pipe and it is more cost effective while performing just as well as a PVC pipe would. We needed some adapters to connect the rubber hose to the pump. For the top tank, we used a windshield washer fluid jug that we thoroughly cleaned. This was a perfect size for our tank and did not cost anything. The 1” flex hose fit perfectly in the one side of the jug. To connect the PVC pipe to the tank we made a hole on the other side and inserted the PVC pipe and used marine silicone to seal it. Just after the tank we added a ball valve to restrict the flow of the water. In the horizontal section of the PVC pipes we made holes where we inserted baskets where the plants

will grow. These baskets are made from a metal mesh. There is a piece of foam at the bottom to hold the seed at first to prevent it from falling out of the basket. We decided to use wood chips as a growing medium since it would absorb a little amount of water and keep the plant hydrated while holding the plant's structure.

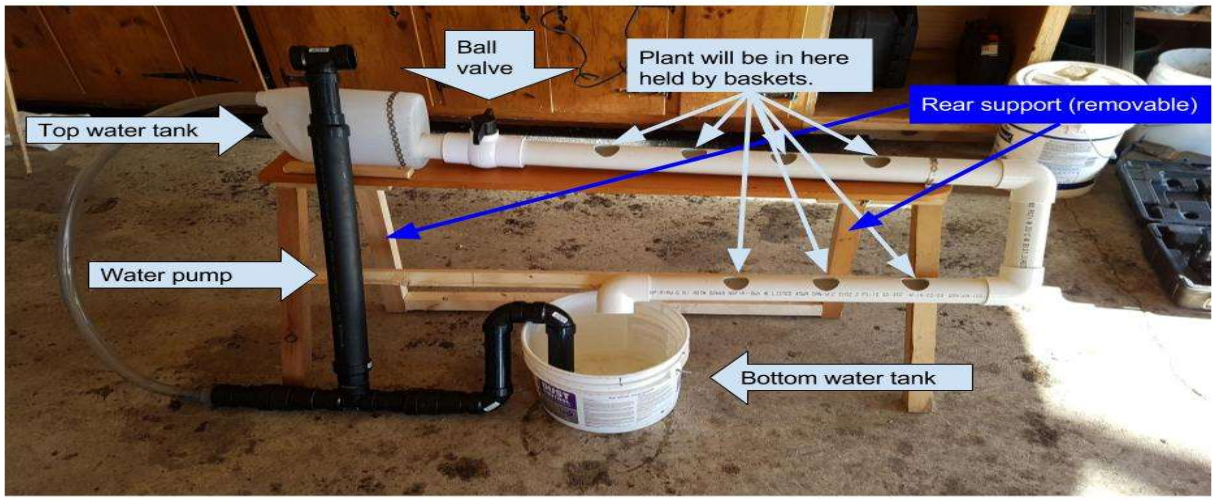


Figure 19: Prototype 3 Completed System

Before we knew all this we just did a simple sketch and determined the material based on our simple sketch which only included the key point of our design which is mentioned above. Those key points were a ball valve, 8 feet of 2" PVC pipe, 3 90º PVC elbows, 3 90º ABS elbows, 2 feet of 1-½" ABS pipe and 4 feet of flex hose. The rest of the material we already owned. We then did some research of these materials and where they could be found and at what cost. Here are all the components we bought at the cheapest price we could find them:

- 1- 2" PVC pipe of 10' $17.90
- 3- 2" PVC 90° elbow $1.46 x3
- 1- 2" PVC ball valve $12.67
- 1- 2" to 1-½" ABS reducer $2.19
- 3- 1-½" ABS 90° elbow $1.28 x3
- 1- 1-½" ABS thread fitting $1.39
- 1- PVC glue $3.49
- 1- 1-½" to 1" reducer $3.71

What really cut down on our cost for this prototype was that we already had built the pump and when testing we concluded that it was sufficient for our third prototype. Also, both of our water tanks were cost free and the wood was also free. All together we spent 56.01$ on our third prototype. We ended up being under budget since we had allocated 70-80 for this prototype. This is good because we went over budget for our second prototype.

Once we had all bought our material and built the prototype we made a test plan. The testing process will go as followed, we will first build the prototype after having bought all the

required material, mentioned in the previous paragraphs, then we will take our prototype outside or in a garage where it does not matter if water spills everywhere. We will setup our prototype as shown in Figure 1 and pour water in the bottom pail. We will then pump water to the top tank with the air pump and another member will measure the time it takes to fill up the tank. We will then let the water flow through the system back down to the bottom pail and measure the time it takes for all the water in the tank to flow through the system. Then we will measure the time it takes for the growing medium to become completely dry. We then repeat the tests 3 more times to make sure our results are consistent and that none of the tests were a fluke. We then record our results in a table and perform simple mathematics to solve the water flow rate through the system.

5.3.1 Test

Our testing objective was to ensure that the water would flow through all the system. Before testing we established that failure could happen if there was leakage somewhere in our system. Failure could also happen if the pump could not push the water up to the top tank due to the gravity. Also, is the ball valve stops working it would fail our test. Finally, our last possible failure was that there would be a blockage in the pipes that would restrict the flow.

To summarize this, what we tested was the water flow rate. First, how long it took to fill the top tank, then how long it took to fully empty the top tank into the bottom tank. Finally, we measured how long the growing medium and sponge would stay wet. Here are our results:

Table 7: Time Needed to Fill Up the Top Tank

Test 1	17.48 seconds
Test 2	13.98 seconds
Test 3	14.73 seconds
Test 4	17.00 seconds

Table 8: Time Needed to Empty the Top Tank

Test 1	Fully open	7.45 seconds
Test 2	Fully open	6.56 seconds
Test 3	½ open	17.50 seconds
Test 4	½ open	19.67 seconds
Test 5	¼ open	58.71 seconds

Finally, we tested how long the basket would stay wet once the water has gone through the pipes. We found out that the basket held water up to 4 hours. When we reached the 4 hour

mark the wood chips and the sponge was still a little damp. We decided to stop the testing since at that point, the medium is not considered “wet”.

In our first test, we ran into a problem which was that when we were pumping the water into the top tank there was nowhere for the air that was already in the tank to go. This caused the seal to break where the PVC pipe is connected to the tank, due to all the pressure that the pump was making. We were able to fix that problem by adding more silicone. To fix the air problem we added a small hole at the top of the tank to let the air out. This is just a temporary solution because we need to figure out a way to let the air out but not the water. From one point of view it is good that this problem happened since it tested the durability of our seal.

The average time that it took to fill the top tank was about 15.80 seconds. To empty the tank, it took about 7 seconds with the valve fully open, 18.59 seconds ½ open and 58.71 seconds ¼ open. Our top tank has a capacity of 3.78 litres which makes the pumps flow rate of 0.24 litres/seconds. The flow rate to empty the tank is 0.54 litres/seconds when fully open, 0.20 litres/seconds ½ open and 0.06 litres/second ¼ open. These tests we performed without any plant in the system so there is nothing to slow down the flow of the water.

After we completed all test we were able to conclude that our system successfully passed the test because the water flowed throughout all the system without any blockage anywhere.

Once we built our prototype we immediately seeked feedback from our potential customer. For our third prototype, we were able to get feedback from two different customers. Our first customer, who has profound knowledge of hydroponics liked our product. He suggested that, when we first start to grow the plant from the seed that we do not put any wood chips into the baskets. This will allow the plants to be able to grow freely without having to grow through the wood chips. Once the plant has reached the top of the basket we would add the wood chips to hold the plant in place. The potential customer also noted that our prototype did not have a lid for the bottom tank and without one could deplete our water supply through evaporation.

The second customer we obtained feedback from was a refugee. He was really pleased with what we built but had some minor concerns. What he liked was our pumping system and how it was designed. He also liked the proposed size of our product. One of his concerns was that the size of the holes for the plants might be too small depending on the type of plant. His concern was that the roots would not have enough room in that size of pipe if you are growing tomatoes and other large vegetables. We had explained to our customer that due to our cost restriction we were only able to use 2 inch pipes. He strongly suggested that we should work on a way to reduce the cost of our pump, since it is the most expensive component in the system. If we can reduce the price of the pump we could use spend more resources to increase the diameter of the pipes to allow the user to grow larger sized plants. With all this being said, our customer really liked our design but would like to be able to grow larger plants, which means that we need to reconsider the amount of money we spend on each sub-component.

Based on our feedback for prototype 3, our designs and concept were well received with few concerns over final dimensions and criteria of our finished product. These concerns were about the cost and size of our system and instructions for our customer. To move forward to a final product, we will need to research ways to cut down on costs while also increasing the size of our system. Prototype 3 was able to stay within budget but this was mainly because of readily

available material rather than purchasing new material. To reduce costs for our customers we will have to research cheaper materials that we can buy in bulk, and research lower manufacturing costs. Since prototype 3 was scaled down to remain under our budget we have not finalized dimensions and allocated costs for our final product. We also need to perform more test to measure the flow rate of the water with plants in our system and verify that the metal straps are strong enough.

6. Conclusions and Recommendations for Future Work

Through using the design thinking process to complete a hydroponic system there are many lessons that our group has learned but, there are also many improvements that could be made. The lessons we have learned are to have better time management, more emphasis on planning, and further testing and research.

Time management is essential to the success of any individual or group in their work. For our group, better time management would have made our prototypes and deliverables better. However, because of the dependencies of the consecutive parts of this project it made time management difficult. Thus, our group submitted many deliverables close to the deadline.

According to our feedback from our potential clients and judges from design day it was made clear that we needed to do some more testing. For example, information about the nutrient solution and how it affects our system. A supplementary filtration system could have been tested if there were less time constraints. In the future, we plan to do more testing to figure out the best nutrient solution to be used for our system with attention to weather and life conditions in Jordan.

The organization of the group determines the work quality and efficiency of doing the work as a group. An important lesson that we learned from this project was to try to plan a more realistic schedule. When devising the project schedule, we should have taken into consideration everyone's personal schedule and tasks that everyone had outside of this course. This would have helped us divide work more effectively. Lastly, we did not plan enough for all potential risks that could be detrimental to our work for example, prototype 2 exceeding our allotted budget and unforeseen circumstances that prevented us from meeting with our client Mohammed Ali.

In the future, we would have built and tested a larger scale prototype to better represent our envisioned final product. We were unable to build a larger prototype due to budget constraints and would research other materials that can reduce the cost of the project while having the same performance. Our previous prototype had issues with leaking because of insufficient sealing. The problem occurs because of manufacturing errors and our group would need to devise a solution to mitigate this. Some considerations are drilling a hole on the top of the top water tank to reduce pressure when a user pumps, and a proof for leakiness. Overall, our design was successful and received positive feedback with minor concerns.

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